Impact of Improved Combat Casualty Care on Combat Wounded Undergoing Exploratory Laparotomy and Massive Transfusion

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Background: Studies have shown decreased mortality after improvements in combat casualty care, including increased fresh frozen plasma (FFP):red blood cell (RBC) ratios. The objective was to evaluate the evolution and impact of improved combat casualty care at different time periods of combat operations.
Methods: A retrospective review was performed at one combat support hospital in Iraq of patients requiring both massive transfusion (≥10 units RBC in 24 hours) and exploratory laparotomy. Patients were divided into two cohorts based on year wounded: C1 between December 2003 and June 2004, and C2 between September 2007 and May 2008. Admission data, amount of blood products and fluid transfused, and 48 hour mortality were compared. Statistical significance was set at $p < 0.05$.
Results: There was decreased mortality in C2 (47% vs. 20%). Patients arrived warmer with higher hemoglobin. They were transfused more RBC and FFP in the emergency department (5 units ± 3 units vs. 2 units ± 2 units; 3 units ± 2 units vs. 0 units ± 1 units, respectively) and received less crystalloid in operating room (3.3 L ± 2.2 L vs. 8.5 L ± 4.9 L). The FFP:RBC ratio was also closer to 1:1 in C2 (0.775 ± 0.32 vs. 0.511 ± 0.21).
Conclusions: The combination of improved prehospital care, trauma systems approach, performance improvement projects, and improved transfusion or resuscitation practices have led to a 50% decrease in mortality for this critically injured population. We are now transfusing blood products in a ratio more consistent with 1 FFP to 1 RBC. Simultaneously, crystalloid use has decreased by 61%, all of which is consistent with hemostatic resuscitation principles.
Key Words: Trauma, Hemorrhage, Massive transfusion, Damage control resuscitation.

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The first combat medics date back to the Knights of St. John during the 11th century crusades.[1] They were trained by Arab and Greek doctors, treated wounded on both sides and evacuated casualties by horse drawn carriages to nearby tents for treatment. Napoleon's Surgeon-in-Chief, Dominiquie Larrey, developed "flying ambulances" and revolutionized the transport and care of combat wounded nearly 800 years later.[2] Colloid-based resuscitation was first documented in the treatment of burned sailors after the attack on Pearl Harbor (1941).[3] The Korean War (1950–1953) witnessed the development of helicopter-ambulances, which were refined to DUSTOFF units during the Vietnam War (1959–1975).[4,5] In 1995, Forward Surgical Teams (FSTs) were developed from lessons learned during Operation Desert Storm (1990–1991), which allowed surgical capabilities close to the front lines. Since that time, trauma system development, performance improvement projects, and bench research have led to myriad changes in the training and capabilities of combat medics and the treatment of the combat injured patient.

These advances in medicine and lessons learned by providers during conflict are frequently translated to civilian practice, such as air ambulance systems, factor VIIa, and the reemergence of tourniquets to name a few.[6–8] The importance given to evidence-based medicine in the 20th century has not only allowed improved dissemination of information to civilian providers but has also improved the translation of advances in combat care to the civilian sector and generated discussion and investigation into the biological processes at work that would otherwise not be possible.[9–12]

At the beginning of Operation Iraqi Freedom, a mobile fighting force necessitated a mobile casualty evacuation system and far forward surgical capabilities.[13] As the battlefield matured to a protracted battle with insurgents, fixed hospitals with advanced surgical capabilities became available and the trauma system in theater matured as well.[14] The protracted nature of today's conflicts has allowed multiple improvements throughout the casualty evacuation chain. Additionally, the advent of the idea of hemostatic resuscitation was developed and its impact on mortality elucidated.[10] The purpose of this study was to evaluate the evolution and impact of the hemostatic resuscitation paradigm at different time periods during combat operations.

MATERIALS AND METHODS

A retrospective review of all patients treated at a single combat support hospital (CSH) in Iraq was performed. Patients were divided into cohorts based on the time wounded:

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the first cohort (C1) was treated between December 2003 and June 2004, and the second cohort (C2) between September 2007 and May 2008. Data were obtained from on-site at the CSH, the Joint Theater Trauma Registry (JTTR) maintained at the United States Army Institute of Surgical Research, and the Joint Patient Tracking Application. The JTTR is a Department of Defense database established to prospectively collect data from multiple clinical and administrative systems. The Joint Patient Tracking Application is a Department of Defense application to record a patient's progress from the battlefield through recovery or death. A retrospective cohort analysis was performed on consecutive patients who required an exploratory laparotomy for abdominal injury and a massive transfusion (MT).

Demographic, laboratory and physiologic data, as well as transfusion requirements were obtained and outcomes were determined. Blood transfusions consisted of packed red blood cells (RBC), fresh whole blood (WB), or a combination of both, fresh frozen plasma (FFP), and platelets. Transfusion requirements were obtained from the JTTR and MT was defined as ≥10 units of blood in the initial 24 hours after admission. Patients were excluded if they were treated at another medical facility before transfer to the CSH, age younger than 18 years, or designated as a security internee.

Data compiled for analysis included demographic data, mechanism of injury, admission vital signs, admission laboratories, Military Injury Severity Scores (MilISS), and mortality. Additionally, transfusion (RBC, FFP, and WB) and fluid (crystalloid and colloid) requirements during the first 24 hours after admission were obtained. Vital signs and laboratory results taken on admission were systolic blood pressure, pulse, respiratory rate, Glasgow Coma Scale, temperature (°F), hemoglobin (Hgb), platelets, base deficit, and International Normalization Ratio. Recorded vital signs and compiled laboratory results were the earliest available after admission. Blood values were measured using standard clinical chemistry techniques or i-STAT (Abbott Point-of-Care, Princeton, NJ). Total transfusion requirements in the first 24 hours after admission included all blood components (units of RBC, FFP, and WB). WB was calculated as 1 unit plasma, 1 unit RBC, and 1 unit platelet. Cumulative FFP:RBC ratios were calculated, as previously described, at three different time points: emergency department (ED), operating room (OR), and at the end of the first 24 hours.[10] Mortality was also compared among the two cohorts. Additionally, total factor VIIa use during the initial 24 hours after admission was obtained. Individual MilISS scores were calculated from patient medical records according to published guidelines.[15,16]

Microsoft Office Excel 2003 (Microsoft Corp, Redmond, WA) was used for database construction. Continuous variables were compared with a Student's *t* test or Wilcoxon test and categorical variables were described with chi-square analysis using SPSS 16.0 (Cary, NC). Variables are expressed as mean ± standard deviation and statistical significance was set for a $p < 0.05$.

RESULTS

Thirty consecutive laparotomies requiring MT performed between December 2003 and June 2004 and 66 between September 2007 and May 2008 were reviewed. Vital signs and laboratory data values of the patient population are presented in Table 1. The C1 and C2 groups had similar MilISS. The C1 cohort presented more hypothermic, anemic, and acidotic than the C2 cohort (Table 2).

Mechanism of injury was recorded as gunshot wound, motor vehicle crash, crush, or explosion as shown in Table 3. Explosion injuries included improvided explosive device, mortar, rocket, rocket- propelled grenade, and grenade. The C1 and C2 groups were equally likely to be injured by an explosion compared with the other mechanisms ($p = 0.514$).

The patients in C2 received more RBC and FFP in ED and more FFP and platelets in OR. The C1 cohort received more RBC and crystalloid in OR than the C2 cohort. Among the cohorts, time spent in ED and OR was similar. There was no difference in transfusion of RBC, FFP, or platelets after OR in the first 24 hours. Overall, there was no difference in the total amount of RBC, FFP, or platelets transfused between the two cohorts (Table 4).

The FFP:RBC ratios at three different time points were calculated; in the ED, OR, and overall for the first 24 hours (Table 5). The C2 group received a ratio closer to 1:1 in OR, and in the first 24 hours than the C1 group. In addition, factor VIIa use was not statistically different between the two groups (0 mg ± 1 mg vs. 1 mg ± 2 mg, $p = 0.459$).

Three cumulative FFP:RBC ratio groups were created: low (FFP:RBC ≤1:4), high (FFP:RBC ≥1:2), and medium

TABLE 1. Patient Variables

Demographics	
Age (yr)	30 ± 16
Military ISS	29 ± 16
Vital signs	
SBP (mm Hg)	96 ± 36
Pulse (bpm)	123 ± 31
Respirations (per min)	28 ± 18
GCS	11 ± 5
Temperature (°F)	96.2 ± 7.9
Laboratories results	
Hgb (g/dL)	10.4 ± 2.6
Plt (10^3 cells/mm^3)	216 ± 120
INR	1.8 ± 1.0
Base deficit (mEq/L)	−2.5 ± 12.2
pH	7.2 ± 0.2
Blood products	
RBC (units)	22 ± 12
FFP (units)	15 ± 11
Platelets (6 packs)	3 ± 6
Fluid administration	
Crystalloid (L)	5 ± 4
Colloid (mL)	337 ± 371

SBP, systolic blood pressure; GCS, Glasgow Coma Scale; INR, International Normalization Ratio.

Data were presented as mean ± SD.

TABLE 2. The Patient Population was Split Into Two Groups Based on Time Wounded

	December 2003–June 2004 (N = 30)	September 2007–May 2008 (N = 66)	*p*
Demographics			
Age (yrs)	30 ± 11	30 ± 18	0.483
Military ISS	27 ± 17	30 ± 15	0.500
Vital signs			
SBP (mm Hg)	88 ± 35	99 ± 36	0.147
Pulse (bpm)	122 ± 25	124 ± 33	0.621
Respirations (per min)	29 ± 14	28 ± 20	0.310
GCS	10 ± 5	12 ± 5	0.328
Temperature (°F)	94.3 ± 2.9	97.2 ± 9.3	<0.001
Laboratory results			
Hgb (g/dL)	9.3 ± 2.7	10.9 ± 2.4	0.003
Plt (10^3 cells/mm^3)	187 ± 107	225 ± 123	0.178
INR	1.9 ± 0.8	1.8 ± 1.1	0.207
Base deficit (mEq/L)	−13.2 ± 8.3	−9.1 ± 6.1	0.010
pH	7.1 ± 0.2	7.2 ± 0.1	0.025

SBP, systolic blood pressure; GCS, Glasgow Coma Scale; INR, International Normalization Ratio.
Data were presented as mean ± SD.

TABLE 3. Cohorts by Mechanism of Injury

	December 2003–June 2004	September 2007–May 2008
GSW	14 (47)	24 (36)
Explosion	15 (50)	38 (58)
MVC	1 (3)	2 (3)
Crush	0 (0)	2 (3)

GSW, gunshot wound; MVC, motor vehicle crash.
Values inside parentheses are percentages.

(FFP:RBC >1:2 and <1.4). The ratio groups were compared at different time periods, ED, OR, and total, between the cohorts. The C1 cohort was more likely to receive a low ratio transfusion at all three time periods than the C2 cohort and the C2 cohort was more likely to receive a high ratio transfusion at all three time periods (Fig. 1). The C2 group had a lower mortality than the C1 group (Fig. 2).

DISCUSSION

There was a 50% decrease in mortality in this critically injured population. The decrease in mortality results from the evolution of Combat Casualty Care (CCC), which has included a combination of improved prehospital care, trauma systems approach, performance improvement projects, and transfusion and resuscitation strategies.

Prehospital Care

Tactical CCC is a system of prehospital management designed for the acute care of combat injured patients and its tenets have been shown to save lives.[17,18] A multitude of changes to the combat medic curriculum have been made since the beginning of the current conflicts to reflect lessons learned.[17,19–21] One of the major changes is that now combat medics transfuse small boluses to restoration of radial pulse, which may be partially responsible for the improved base deficit seen in the second cohort, although this is speculative because prehospital resuscitation number are not available.

TABLE 4. Transfusion Requirements per Cohort

	December 2003–June 2004	September 2007–May 2008	*p*
ED			
RBC (units)	2 ± 2	5 ± 3	0.000
FFP (units)	0 ± 1	3 ± 2	0.000
Time (min)	144 ± 240	58 ± 49	0.101
OR			
Crystalloid (L)	9 ± 5	3 ± 2	0.000
Colloid (mL)	340 ± 447	335 ± 300	0.254
RBC (units)	16 ± 10	12 ± 10	0.019
FFP (units)	8 ± 7	11 ± 9	0.019
Platelets (units)	1 ± 2	2 ± 5	0.037
Whole blood (units)	1 ± 2	0 ± 1	0.001
Time (min)	173 ± 87	142 ± 80	0.140
Post OR			
RBC (units)	5 ± 6	4 ± 6	0.298
FFP (units)	5 ± 7	3 ± 6	0.275
Platelets (units)	1 ± 2	1 ± 1	0.573
Whole blood (units)	1 ± 2	0 ± 1	0.000
Total			
RBC (units)	23 ± 12	21 ± 12	0.266
FFP (units)	13 ± 10	17 ± 11	0.063
Whole blood (units)	2 ± 3	0 ± 2	0.000

Data were presented as mean ± SD.

TABLE 5. Cumulative FFP:RBC Ratios

	December 2003–June 2004	September 2007–May 2008	*p*
ED ratio	0.238 ± 0.768	0.541 ± 0.17	0.088
OR ratio	0.421 ± 0.312	0.769 ± 0.207	<0.001
Total ratio	0.511 ± 0.32	0.775 ± 0.211	<0.001

Data were presented as mean ± SD.

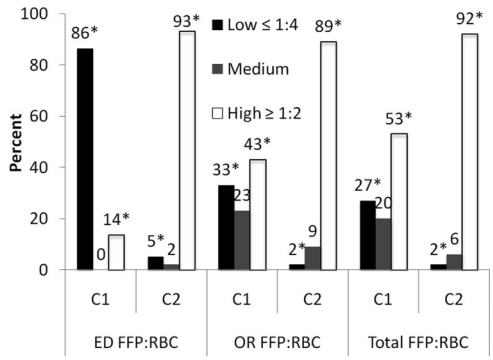

Figure 1. Comparison of FFP:RBC ratio at different time periods. Analysis compares percent in ratio group per time period, i.e., C1 low in ED vs. C2 low in ED. *$p < 0.05$.

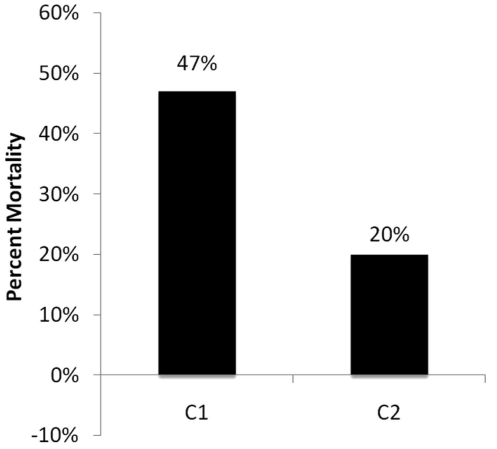

Figure 2. Mortality comparison between cohorts; $p = 0.006$.

Tourniquets have been used in surgery to stop bleeding since 18th century but their use in the prehospital setting was discouraged as late as the 1960s.[22] Tourniquet use has been shown to decrease mortality in combat environments without increasing limb loss.[17,18] The Combat Application Tourniquet (Composite Resources, Rock Hill, SC) is the most recent iteration and allows one-handed application by either the battle buddy or the injured soldier, every soldier now carries a C-A-T with them to battle. Increased use of tourniquets likely further contributed to the increased hemoglobin in the second cohort. Further studies are needed to confirm this assumption.

Hypothermia is one part of the "bloody vicious cycle" in trauma patients. As many as 66% of trauma patients arrive to EDs with some degree of hypothermia (temperature <96.8°F or 36°C).[23,20] Hypothermia causes dysfunction of coagulation proteins and exacerbates bleeding. The mortality in combat casualties with hypothermia is double that of normothermic casualties with similar injuries.[20] Hypothermia is a potentially preventable complication of transport and as such, an emphasis was placed on ensuring patients arrive at the CSH normothermic. The use of Hypothermia Prevention/Management Kits (North American Rescue Incorporated, Greer, SC) is now mandatory in all rotary wing evacuation and ground evacuations, it includes a number of devices for passive rewarming. In addition to using the Hypothermia Prevention/Management Kits, other measures to prevent hypothermia include Temp dots placed on patient's foreheads, Thermo-Lite Hypothermia Prevention System Cap (Encompass Techstyles, Addison, TX) placed on the casualty's head, and hypothermia prevention and reversal strategy development during pre-mission planning. The resuscitation of casualties with warmed IV fluid has also contributed to the improvement in temperature. Combat medics are now even trained to use Meal Ready to Eat heaters to warm IV fluids (www.usaisr.amedd.army.mil/cpgs/HypothermPrev0811.pdf).

Trauma Systems Approach

The military trauma system is set up for tiered evacuation with increasing capabilities at each level. Level I is combat medic or battle buddy treatment, Level IIa facilities are Troop Medical Clinics. Basic surgical capabilities are available at Level IIb FSTs. The CSH, Level III, has a wide array of diagnostic and advanced surgical capabilities to include computed tomographic scanners. Patients are evacuated within days of injury from the battlefield to Level IV facilities and eventually to Level V facilities in the United States for definitive surgery, continued critical care management, and convalescence and rehabilitation.

At the beginning of Operation Iraqi Freedom, FSTs were deployed across the country to allow for earlier treatment of injured soldiers.[13] As the battlefield and trauma system matured, FSTs were increasingly co-located with the CSHs to provide advanced surgical capabilities to casualties without delay at a Level IIb facility.

Performance Improvement Projects

Performance improvement projects have been developed in theater to evaluate deficiencies and improve care.[14] At a Level V facility, a number of incomplete fasciotomies were noted in arriving patients, and this lead to a systemic review that resulted in improved instruction in theater and pre-deployment for all surgeons on a procedure rarely done in civilian or peacetime practice. Another example of a performance improvement project was aimed at preventing hypothermia. Anytime a casualty arrived hypothermic, an investigation occurred and feedback given to the chain of care from the CSH to the field medic and company commander. The Joint Theater Trauma System has developed a comprehensive program for identifying areas in which improvement can be made, and by using clinical practice guidelines and feedback mechanisms, remedying the delinquencies.

Transfusion/Resuscitation Strategy

Recent evidence has supported the early use of high FFP:RBC ratio transfusions when it was noted that they were associated with reduced mortality, especially in massively transfused patients.[10] In March 2006, a clinical practice guidelines was issued that stressed the importance of adhering to hemostatic resuscitation principles to include early use of FFP, 1:1 plasma to RBC transfusion, and limiting the amount of crystalloid given to patients. The US Army is now transfusing patients with the goal of 1:1 plasma:RBC while also limiting the amount of crystalloid used to resuscitate patients by 61%. This is further confirmation that evidence-based medicine changes in practice are at the forefront of military medicine's treatment of casualties.

The major limitation of this study is its retrospective nature, which does not allow a causative factor to be identified for the improved survival seen in the second cohort. However, as a global snapshot of CCC and the changes that are continuously occurring, it serves as a crude measure of improving casualty care for soldiers, sailors, and airmen.

The US military is transfusing blood products with the goal of 1:1:1 FFP:RBC:platelets, and we are simultaneously limiting crystalloid use. Both of these measures are consistent with hemostatic resuscitation principles. Additionally, patients are presenting to the ED with improved physiologic parameters, likely the effect of improved Tactical CCC, a mature battlefield, performance improvement projects, and an

effective theater trauma system. All these improvements in CCC are associated with a 50% increase in survival in this critically injured subset of patients.

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